SEMI-ANNUAL REPORT

on

OPERATION OF AN MHD POWER GENERATOR

for the period

December 1, 1965 to May 31, 1966

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submitted by

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Abstract

Assembly of the graphite inert gas heater has progressed to the point where the heater will be taken up to temperature in a series of tests over the next few months. Mild problems were encountered during assembly, but indications are that the unit should be reasonably troubled in operation.

A simple design has been chosen for the first experimental channel since it is likely that changes will need to be incorporated as work progresses.

Fairly extensive changes have been made to the design for the D. C. electromagnet. The major change is from H-laminations to C-laminations in order to provide much better facilities for optical studies of the flowing plasma. The iron pole faces have been changed to provide a 6-in. x 10in. gap which is over 40 inches long. The magnet will be available in December, 1966.

Most of the engineering design and a large part of the physical construction have been completed. Increasing attention can now be turned to diagnostic problems with the flowing plasma.

The time schedule for operation is for heater tests during September - October, 1966, cold and hot gasdynamic flows during October - November, hot plasma flows without magnetic fields during December and full-scale operation in the early part of January, 1967.

1. INTRODUCTION

This report is the first semi-annual report written under Grant NGR 52-026-012. This grant is supervised under the guidance of Mr. N. John Stevens, Spacecraft Technology Division, Lewis Research Center, NASA. The grant is for the investigation of operations of magneto-gasdynamic power generators with specific emphasis on low-pressure operation.

Although the grant began on December 1, 1965, work could not be started until May 1, 1966 when graduate students became available as research assistants. This report covers work actually performed during the May 1 - August 31, 1966 period.

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2. MHD POWER GENERATION FACILITY

A general description of the experimental facility can probably best be given by reproducing the abstract of a paper which was to be presented to the IAEA MHD Power Generation Symposium in Salzburg, Austria, July 4-8, 1966. This abstract was submitted in 1965 before the present grant was instituted.

Design and Construction of a Magnetogasdynamic Power Generator

The design features of a supersonic magnetogasdynamic power generation facility are outlined. The generator is essentially an MGD channel operating between two reservoirs whose pressures can be scaled up or down in order to achieve various operating conditions in the channel.

The upstream reservoir is a gas heater comprising a bed of graphite pebbles in a thermally insulated pressure vessel. The vessel is of steel construction, 1.37 m in diameter and 2.74 m in height. The heat transfer core itself is 0.46 m in diameter and 0.86 m in height. Right-cylindrical graphite pellets, 2 cm in height, were selected in order to minimize the pressure drop across the bed under high mass flow rates. Mass flow rates of up to 2-3 kg/s are possible with reasonable rates of decrease in bed temperature. Stagnation pressures of up to 8 atmospheres are possible at stagnation temperatures up to 2500 ^{o}K. The graphite bed is brought up to temperature by radiation from three internal heating tubes. The electrical heating power to these tubes is 120 kW from a 50 V, 1600 A three-phase transformer. Overall, the heater closely simulates a 3-MW nuclear reactor.

The downstream reservoir is a steel vacuum sphere, 13 m in diameter, having a volume of 925 m^3. It is capable of being operated at pressures between 5 and 1000 Torr.

The supersonic diffuser downstream of the MGD channel is formed from water-cooled steel piping. It is connected to a downstream heat exchanger that cools the flow before it is dumped into the vacuum sphere.

The magnetic field will be supplied by an iron-core, water-cooled electromagnet capable of filling a 10 cm x 15 cm x 100 cm volume with a field having an intensity of 2 Wb/m^2.

Initially, a 5 cm x 10 cm flow channel will be installed. Design operation is aimed at Mach numbers of 0.8 and 2.0 by the use of interchangeable nozzle blocks matching the channel inlet. The channel static pressure can be varied between 0.1 and 5 atmospheres.

In supersonic operation at Mach 2.0, the flow speed is of the order of 1.2 km/s, resulting in induced electric fields of up to 2.4 kV/m. This results in open circuit voltages across the channel of up to 240 V.

Detailed diagnostic studies are planned for electric field and current measurements in the boundary layers over the cathode and anode. Studies are also planned for MGD boundary layers on flat plates inserted into the isentropic core of the channel.

Construction of the facility has progressed to the stage where flow tests will soon be started in order to test operation of neutral gas flows.

3. GRAPHITE INERT GAS HEATER

A steel pressure vessel 1.37 m (54 in.) in diameter and 2.74 m (108 in.) in height was designed and constructed to operate at a pressure rating of 100 psig (Figs. 1 &2. A water jacket surrounds the vessel in order to allow operation with personnel in the laboratory. With the graphite core operating at 2500 ^{o}K and the water jacket at 310^{o}K, approximately 30 kW of heat will be lost across the thermal insulation. This sets no upper loss on the heater stagnation temperature since the power input is 115 kW.

During late July, all the preparations had been made for heater assembly, and all the graphite pieces were lowered into the pressure vessel. Some difficulty was encountered with the plates which center the lower head on the six carbon supports. This was overcome by gluing the plates onto the lower head in situs with carbon cement . It is not expected that vibration of the vacuum sphere pumping diesels in the room below will be any problem.

Further difficulties were encountered when it was discovered that the manufacturer of the graphite components had turned down one rim of the lower header too large. This was solved by sandpapering out a two-inch section of the inside bottom of the large outer annulus. This was then fitted down over the lower header with fine strands of carbon string as a seal against lampblack which might tend to blow through the fitted joint. The remaining pieces went together without any serious problems.

The electrical connections between the secondary of the heating transformer and the top of the three graphite heating elements have still to be completed. The temperature of the graphite current-carrying ring in the bottom of the heater will be monitored by an automatic infrared pyrometer. Control of the transformer is automatically carried out by the pyrometer.

The thermal insulation of the heater is complete except for graphite felt padding across the top and sides of the upper head. Some problems are expected with shifting of the lampblack insulation under full-pressure runs. It is felt that these can be temporarily solved by careful loading and unloading of the gas pressure. Eventually the lampblack will be replaced by graphite felt. Cooling water feed and drain lines to the pressure vessel have been completed and tested.

All flow passages in the heater were bored out to a minimum area of 175 cm^2 (28 in.^{2}) before assembly of the heater. The first channel of 8 in.^{2} thus uses only a fraction of the heater's capacity.

Preliminary tests of the heating circuit are planned for early September with sustained temperature operation planned for October.

4. POWER GENERATION CHANNEL

The first channel to be constructed will be a 5 cm x 10 cm channel with uncooled alumina walls. A computer program is being written in order to see if the amount of heat carried down the channel by radiation reflection from the heater will allow the use of uncooled walls during the ten or so hours allowed for heating up and the much longer period for cooling down of the graphite heater. It is suspected that provisions will have to be made for water cooling of the walls.

A subsonic graphite nozzle has been designed and is being constructed. A transition piece tailors the 15 cm I. D. heater outlet to the 5 cm x 10 cm rectangular channel. The channel is a constant area one and hence acceleration to choking of the M = 0.8 flow is expected. A supersonic nozzle will be designed later. Figure 3 shows the range of possible operating conditions in the channel.

Careful attention is planned for studies of the boundary layer growth in the channel. As clean an aerodynamic flow as can be obtained will be aimed at. An early channel of lucite was mocked up and one run taken at about M = 0.5. However, this study was discontinued after July 4th and more effort was put into designing a simple channel of alumina. Hot boundary layer studies will then be able to be done with high temperature pressure probes.

5. ELECTROMAGNET FACILITY

Extensive revisions of the design from that reported in the UTIAS 1965 Progress Report have been made. The major revision has been the substitution of C-laminations for the previous I-laminations. This allows much freer access to one side of the channel for spectroscopic studies.

The magnetic field region has been increased to 15 cm x 25 cm. The 1.8 T field is uniform to about 3% over the 10 cm x 15 cm channel and 5% over the 15 cm x 25 cm gap region. These figures are for flat pole faces and can be improved considerably by gentle sloping of the faces. The pole faces are removable, allowing the creation of a 25 cm x 30 cm gap although with poorer field uniformity.

The current coils are of 10 cm x 20 cm cross-section and are each made up of 144 turns of copper conductor, 1.8 cm x 1.8 cm square with an internal cooling passage 0.625 cm in diameter. There is a copper conductor area of 0.96 cm^2 running at a current density of 870 A/cm^2. Coil power is 38.6 kW each. Figure 4 depicts a recent design without pole shaping.

Contracts have been let for furnishing the magnet and it should be available in about December. Until this time, studies will be done on the uniformity of seeding over the channel area and on electrical conductivity in the absence of a magnetic field.

3. DOWNSTREAM HEAT EXCHANGER

More recent thinking has led to consideration of a water-cooled heat exchanger downstream. A graphite bed would work but the rates of temperature rise at large argon mass flow rates might allow some of the seed material to pass out into the vacuum sphere without condensing on a cold surface.

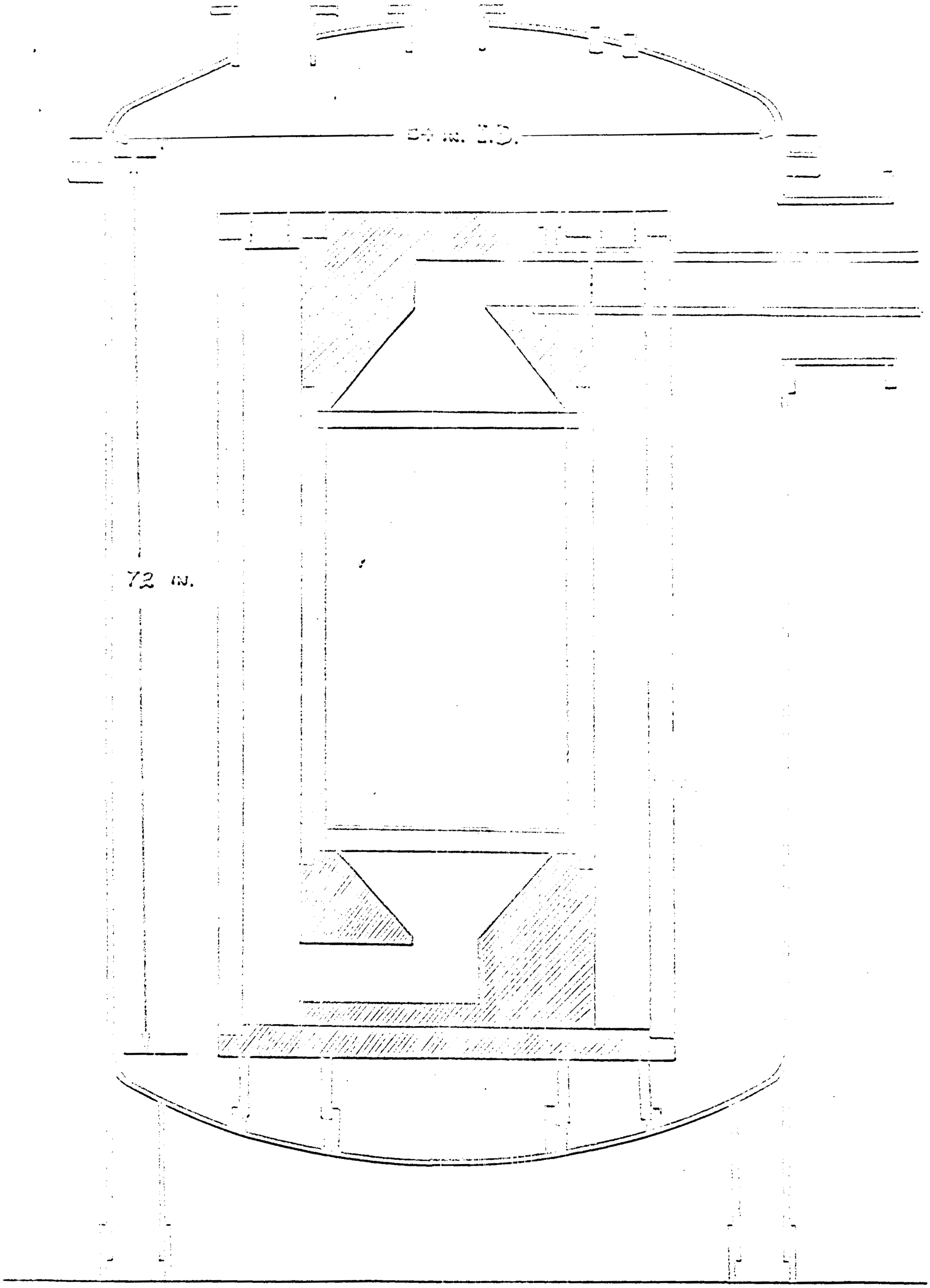

FIG. 1: CROSS-SECTIONAL VIEW OF GAS HEATER

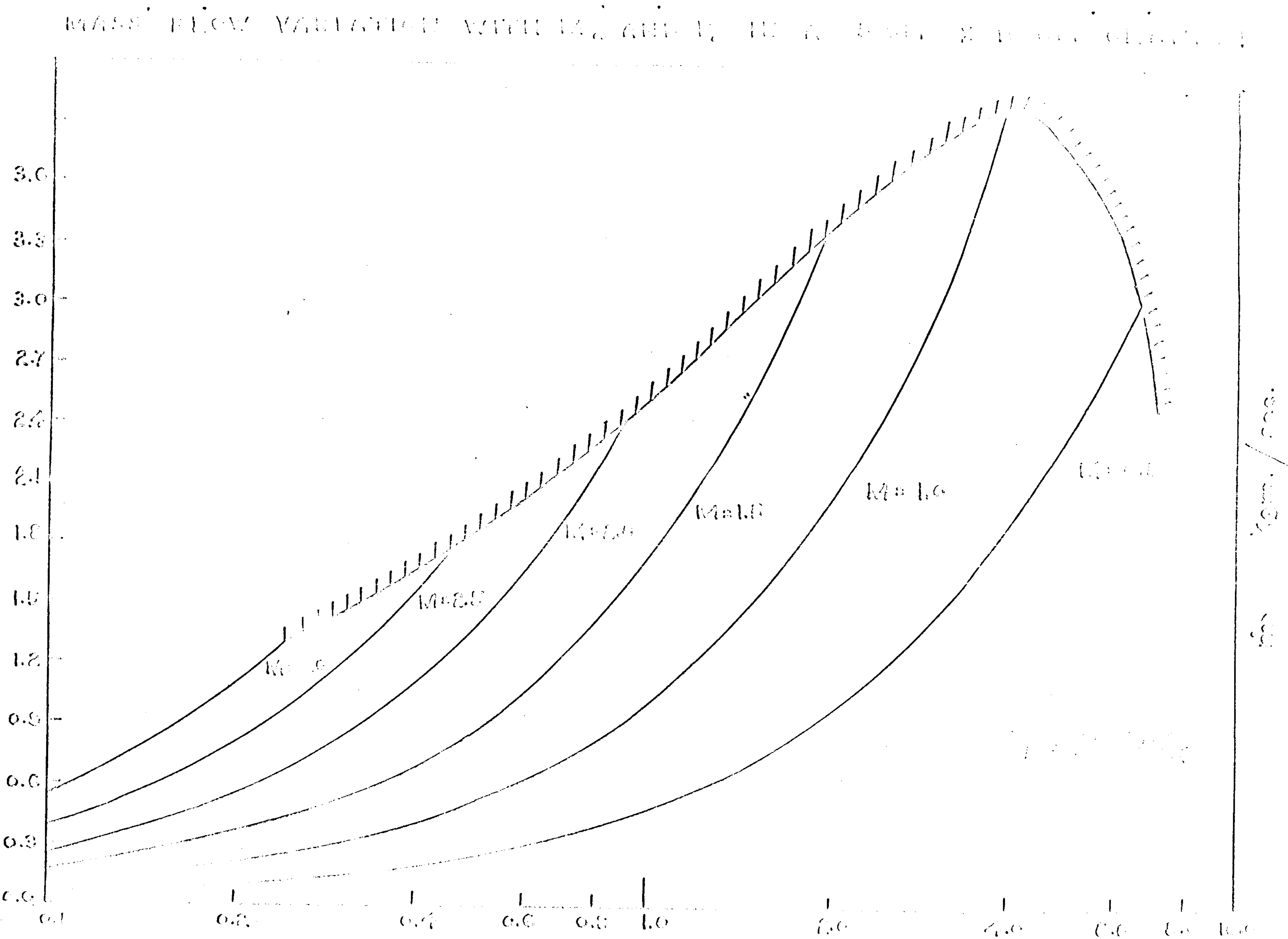

FIG. 3: P_c CHANNEL ATMOSPHERES

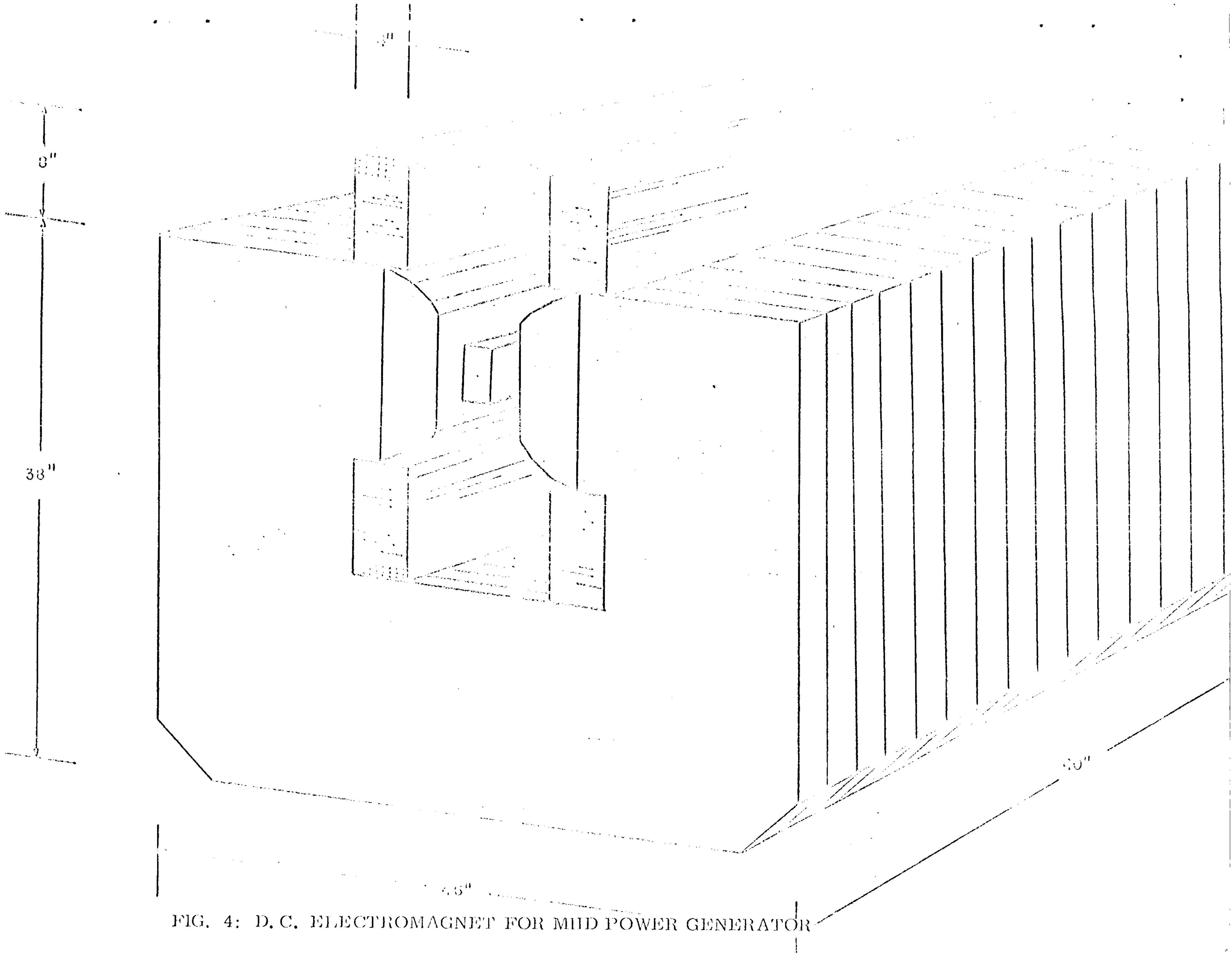

FIG. 4: D. C. ELECTROMAGNET FOR MHD POWER GENERATOR